Chapin (C. V.)

The Purification of Public Water Supplies

An Address Delivered before the
Rhode Island Medical Society
June 1, 1893

By CHARLES V. CHAPIN, M. D.

presented by the author

FILTRATION OF PUBLIC WATER SUPPLIES.

An Address Delivered at the Annual Meeting, June 1, 1893,

BY

CHARLES V. CHAPIN, M. D.,

OF PROVIDENCE.

An adequate supply of suitable water is one of the first needs of a modern city. In order to be suitable the public water supply must meet several requirements. In the first place it must be adequate, so that there shall in no case be any danger of a water famine. There must be enough for all purposes; not only for domestic uses, but for fire purposes, for street sprinkling, steam boilers, elevators, etc. In the second place the water should have certain desirable chemical properties. It must not be too hard; it must not corrode or form a scale in steam boilers. Then—and what is for our consideration the most important of all—the water must be wholesome; it must not exert any injurious effect on the health of those who use it; it must not carry with it the germs of disease. Moreover the water must meet certain æsthetic requirements. It is desirable that it should be as nearly colorless as possible, and it is absolutely essential that it shall have no offensive odor or taste.

As regards the quantity of the supply, American cities have taken the foremost rank. Although the principal city of this State presented the unique spectacle of attaining a population of nearly 75,000 people entirely dependent upon wells for their water, now, however, three-fourths of the people of the State make use of a public water supply. The amount of water consumed in American cities is nearly twice as great *per capita* as that consumed in European cities; a large portion of it, however, is a needless waste, as has been shown by the history of those cities that make use of meters, as Providence, where the *per capita* consumption is

moderate, and yet there is no question but that every one here has a sufficient quantity of water.

As regards the chemical composition of the water, of course this depends largely on the geological formation of the water-shed from which the water is derived. In this part of the country most of the surface waters are soft and free from injurious salts of any kind. This is certainly so in Providence, whose water supply is most excellent for laundry and boiler purposes.

That water is often the carrier of disease is one of the best established facts of modern sanitary science. Forty or fifty years ago it was demonstrated beyond a doubt that cholera and typhoid fever are disseminated by this means, although the exact nature of the virus of these diseases was not at that time known. The discovery of the causative relation of various forms of bacterial life to the infectious diseases has only served to furnish additional proof of what was well known before, and to explain many of the conditions which were not so thoroughly understood. The researches of Prof. Koch in India and Egypt demonstrated the presence of the cholera organisms in water which had been shown to be the cause of the disease, and numerous investigations in Europe and in this country have demonstrated typhoid baccilli in drinking water as the cause of epidemics of typhoid fever. Four years ago the writer presented to you an account of epidemics of typhoid fever in several American and European cities, including Providence, which were demonstrably due to the specific pollution of the public water supply. Since that time many other instances have been recorded, notably epidemics at Lowell, Lawrence and Newburyport, all due to the pollution of the Merrimac River, and at Chicago due to the pollution of the lake water with the sewage of the city. It has also been shown that the epidemic of cholera in Hamburg last summer was due largely to specifically polluted water. It is quite possible also that other diseases, such as malaria, diarrhœa and dysentery, which are produced by micro-organisms, may be transmitted in drinking water, but the case has never been made out so clearly as for typhoid fever and cholera. It can be positively asserted, then, at the present time, that certainly cholera and typhoid fever, and possibly other parasitic diseases of a similar character, can be carried in drinking water, the active factor in the production of these diseases

being of course the living organisms themselves. We know that these minute parasites produce the symptoms of the disease largely through the formation of chemical products such as the ptomaines and toxins, but there is no evidence to show that these products of the ordinary pathogenic organisms ever exist in drinking water in sufficient quantity to affect the health of the users. It is true that instances have been reported where the dark colored water of Southern swamps, rich in nitrogenous materials, has been supposed to be the cause of gastro-intestinal disorders, and there is no question but that the ingestion of sewage or water considerably polluted by the same has been productive of disease, and the diseases in these cases were due not to the presence of pathogenic organisms in the body but to the action of the chemical substances in solution in the water. In almost all these instances, however, the water was so polluted as to be to the unaided senses manifestly unfit for drinking, and always an ordinary chemical analysis would indicate the very unusual amount of the organic constituents. Certainly the public water supplies of this State do not contain a sufficient amount of any form of organic material in a state of solution to produce any effect upon the health of the users.

The odor and taste of water is of considerable importance. It not unfrequently happens that public water supplies are rendered obnoxious from the presence of certain odors and particularly tastes which have been variously described as "woody," "musty," "fishy," "cucumber," "green-corn," etc. This has happened in the water supplies of Boston and New York city, and in those of a vast number of other towns both in this country and in Europe. The water possessing these characters is entirely unfit for drinking purposes, but there is no good evidence that it is likely to be productive of disease or of any unpleasant symptoms except in delicately constituted invalids. It has been shown that these tastes and odors are almost invariably due to the growth and subsequent decay and death of minute organisms in the water, chiefly algæ, but sometimes fungi. These growths usually occur in shallow reservoirs built on sites containing a large amount of organic matter, but they may occur in deep reservoirs, in driven wells, and even in the distributing pipes. These organisms belong to the vegetable kingdom, and are mostly algæ, this term including such species of whatever family of the lower order of plants as are provided

with chlorophyll in its various forms. Most of these are much larger and have a higher organization than the bacteria. Some of the fungi closely allied to the bacteria and possessing no chlorophyll are, however, sometimes the cause of very serious pollution of the water, as crenothrix, which produced the well-known "calamities" of Berlin and Rotterdam. The number of species which produce disagreeable odors and tastes is very great, but their presence does not always result in altering the taste of the water. It is probable that they must be present in exceptionally large quantity, and furthermore that they must undergo rapid death and decay in order to produce the conditions referred to. They are veritable pests of water works and are wisely dreaded by all water engineers. Much remains to be learned in regard to their laws of growth, but it is known that they are much more likely to occur in water containing a large amount of organic matter, and especially when this is stored in shallow reservoirs. Certain species also seem to require particular chemical ingredients in the water, as iron, sulphur, lime, etc. Besides the bacteria which are directly productive of disease and the algæ just mentioned, various forms of animal life are found in waters. Among these may be mentioned numerous species of infusoria, minute crustacea, such as water fleas, and of course larger forms, such as various fish, reptiles and mollusks, occur. Some of these forms are probably occasionally of value in serving to make way with the dead vegetable material in waters which contain much of such material, but there is no reason to think that it is not in the long run in ordinary waters most desirable to have all forms of animal and vegetable life removed as far as possible, at least from the distributing service.

The color of water, while not in any way affecting health so far as we know, is of importance, for every one likes to drink a colorless water, and it requires much argument to persuade people to drink a dark colored water though it may be known to be pure, in preference to a colorless water which is known to be dangerously polluted. So, too, the presence of suspended mineral matter, as clay and silt, or of vegetable debris, in water, renders it unpleasant, and should not be tolerated in any quantity in a public water supply.

The undesirableness of a water supply may then be due to the presence of pathogenic bacteria, of algæ and other

vegetable organisms, of animal forms of life, and of other suspended matters of any kind; also to disagreeable colors or odors; and the presence of an undue amount of such inorganic materials in solution as will injure the water for boiler and laundry purposes. The recognition of color, odor, taste, and suspended matter is of course easy to the unaided senses; the recognition of corroding and scale-forming properties is readily made by means of the ordinary chemical tests; and the determination of all the important forms of organic life is now rendered possible by the exact methods of biologic science.

From the physicians' standpoint it is by far the most important to determine whether or not a water is or is not likely to be the carrier of disease. Before the discovery that the cause of the specific diseases is some form of bacterial life, it was, as has been said, demonstrated beyond question that water contaminated with sewage and human excrement was often the cause of the appearance of various epidemic diseases. To determine whether a given water was or was not the carrier of disease, or was likely to be such, taxed for many years the ingenuity of chemists, but it was ultimately determined that in a general way certain ingredients gave an indication of the amount of contamination and presumably of the relative danger of different waters. The ingredients which were thus used as indices of the potability of waters were chlorine and the various forms of combined nitrogen in albuminoid and free ammonia, nitrites and nitrates. Of course it was well recognized, particularly by sanitarians and physicians, that the presence of these substances was merely an index, though a very fair one, of the degree of pollution which might or might not be injurious to health, the danger depending entirely upon the sources of the organic material which gave rise to these substances. But this method of testing water was for so long the only one known to science and in so many instances gave such good results that many practical chemists thought that these materials themselves were the dangerous ingredients in the water, that they were not merely the indication of something else. We now know that while it is not certain that dead and dissolved organic matter never gives rise to bad symptoms, "albuminoid ammonia" is not in itself productive of disease, at least as it occurs in ordinary water supplies, such as are furnished to

the inhabitants of this State. Thanks to the researches of Pasteur and Koch we know that the disease producing agents are bacteria, and the methods devised by Koch have rendered their determination easy by those who are skilled in his methods. The attempt to classify waters as to their wholesomeness by means of a quantitative determination of bacteria cannot, of course, be more than partially successful.

The mere number of the bacteria, just as the simple determination of the ammonia and nitrates, can only furnish a rough *indication* of the degree of pollution. The determination of the species of organisms, however, does give much more definite information. If the organisms present are simply those characteristic of natural waters, and there are many such, the number may be quite large, and yet the water may be perfectly harmless. If, however, organisms be found that are characteristic of human or animal excretions, certainly the water is dangerous. It is not that at that particular moment the water is dangerous, but if there is evidence of excremental pollution it is clear that there may be at any time infection by the disease-producing bacteria.

The critical inspection of the source of a water supply gives in many instances a better indication of its character than even a biological test. If fæcal matter goes into the water that we drink it is certain that the water is dangerous, even if the ammonia and nitrogen be small in quantity and the bacteria be few in number and for the time being of harmless species.

The ultimate source of all our water supplies, of course, is the rain, and this as it falls upon the earth is doubtless without dangerous pollution. Sometimes the rain water does not penetrate the surface of the soil at all, and oftentimes it penetrates only for an extremely small distance. Such waters are properly called surface waters. Often, on the other hand, the rain water soaks into the soil and passes through it for very considerable distances. It then becomes ground water. Surface water after flowing on the surface or remaining on the surface for any length of time may become ground water. The chemical and biological characters of surface waters and ground waters differ decidedly. The surface waters usually contain a certain amount of organic material in the form of proteid or albuminoid matter which gradually undergoes an oxidation into ammonia,

nitrites and nitrates; ground water usually does not contain much albuminoid material, as it has by its slow passage through the soil been oxidized into nitrates. The surface waters are usually soft, while the ground waters are rendered hard by the mineral constituents which they dissolve from the soil. Surface waters contain the various living organisms, both animal and vegetable, which have been referred to; ground waters contain very little life and are often absolutely sterile. In other words, the rain which falls from the clouds, by its passage over the surface of the land and remaining upon it, takes up considerable organic matter in solution and suspension, and serves as a suitable medium for the growth of many organisms, while water that filters slowly through the soil is deprived in great part of these matters, and in their stead takes up non-organic matter from the soil.

Municipal water supplies are sometimes taken from the ground water, as in the case of wells and springs; but in such cases it is apt to be too hard. In the great majority of instances, however, it is only possible to supply a sufficient amount of water by taking the surface water from rivers or lakes. This is the case in all the water supplies in this State. The surface waters in this State not only take up vegetable material, which, though causing considerable color and some odor, is not injurious to health, but they are subject to a certain amount of dangerous pollution of an excremental character. The Pawtuxet River receives pollution from certain privies and sink-drains, and, flowing through a thickly settled region, as it does, is always liable to receive a certain amount of accidental pollution of this nature in times of flood. It also receives a considerable amount of manufacturers' waste, which, though not injurious of itself, yet if the amount should be sufficient would so increase the organic matter in the river that it would become favorable for the growth of many of the lower forms of vegetable life. The water supply of Providence has been known to contain typhoid bacilli, and there is no reason why this organism may not gain access to some of the other supplies.

The shoal ponds and reservoirs from which all our waters are largely drawn are favorable to the growth of algæ and the production of the unpleasant odors and tastes which result therefrom. Fortunately, as a matter of fact, we have

not, in Providence, suffered very much from this cause. Our waters do not contain much mineral matter in suspension, and are not hard; but there is considerable vegetable matter in suspension at times which gives quite a dark color.

The principal factors of pollution in our water supplies are then:

1 (and foremost). The presence of pathogenic bacteria.

2. Of algæ and other non-pathogenic organisms.

3. Of other matters in suspension.

4. Of coloring matter.

Before proceeding to a consideration of the purification of water, I would say that all must agree that it is desirable if possible to obtain a supply from a source which is unquestionably without any danger of injurious contamination; but if for engineering or financial reasons this is not feasible, it becomes of vast importance for us to determine what is the value of natural or artificial methods of improving the character of a given water. A great deal has been said and written about the self-purification of rivers, and both the advocates and opponents of the theory that rivers readily purify themselves have taken a very firm stand in the matter. The question, however, is not one which is easily settled. A great many factors must be taken into consideration before we can reach a just conclusion. The question of dilution is an important one. A polluted stream may apparently become purified when in reality there is simply a dilution owing to the addition of pure water either from tributaries or from springs. On the other hand a river may apparently continue without showing any signs of improvement, the improvement being masked by the addition of pollution at various places. Then, too, rivers have shown a falling off in their organic constituents due entirely to a sedimentation of the solid particles of the organic matter, the dissolved portion really indicating an increase; while, on the other hand, an increase, in albuminoid ammonia has been noted which has been due to the growth of algæ and the like feeding upon the dead and dissolved organic matter. The changes just spoken of refer to the chemical purification, and it is this which has received by far the greatest attention from chemists and water engineers during the past.

A study of the biological self-purification of rivers has been made in only a very few instances. The most careful experiments in regard to this self-purification of rivers have

been made in the Blackstone below Worcester, by the Massachusetts State Board of Health; in the Thames by Percy Frankland; in the Spree at Berlin, and in the Limmat at Zurich. I think that as a result of these various experiments we may fairly conclude that a diminution of the organic material, particularly by the sedimentation of minute solid particles, but partly through the oxidation of the dissolved organic matter, takes place; that this improvement in the great majority of cases is, however, of not very great importance. In regard to bacteria there is also sometimes evidence of a considerable improvement as regards the number found in a river. There are two reasons for such diminution which will be referred to more fully farther on. The two causes at work are, first, the death of the organisms which may be expected to occur in water which is not seriously polluted; second, their precipitation together with other particles to the bottom of the stream in case the current is not too rapid. Their death, of course, is a positive gain, but their precipitation is not necessarily so, for it has been shown that the next flood may sweep them from their bed, resulting again in an increased number of these organisms floating in the water. It has been shown that the improvement which has sometimes been noted in streams is thus due chiefly to the element of time. If the river flows slowly enough, a certain number of bacteria will die and a certain number will be precipitated, and there will be a certain amount of dead organic matter oxidized by the various chemical and biological changes which are going on in the stream. It is due to this partial improvement as regards the bacteria in the water that the mortality from typhoid fever and similar diseases is not greater than it is in those cities which are supplied with water from a polluted source. The tendency undoubtedly in such cases is towards a steady improvement in the river water the longer it flows.

The æration of the water of rivers in falling over dams and natural obstructions has been supposed to exert an important influence in purification, but this supposition is not correct: for while dissolved oxygen is necessary for the working of certain purifying changes, an excess of oxygen, introduced by however so efficient æration, has been shown not to extend such process.

In fine it can be stated that, while the self-purification of rivers, both from a chemical and biological standpoint, is to a limited extent well established, it cannot as a matter of fact in practice be relied upon to render a water which has been polluted by excrementitious matter safe for people to drink; and apart from all theoretical and experimental considerations this has been demonstrated by facts in the case of Philadelphia, Providence, Lowell, Lawrence, Hamburg, Berlin, and many other cities.

Seeing that the natural purification of rivers cannot be relied upon to furnish us with pure water, let us see if there are any artificial methods which can render our drinking water less dangerous or perhaps safe. There are several methods employed for the improvement of water which are open for consideration.

1. Storage. Though in many cases, perhaps in all cases, the building of large storage reservoirs has been for the purpose of storage simply, and not with the idea of improving the quality of the water, it has been proved that such storage in many cases is of very great benefit. It has been shown by experience that most of the pathogenic bacteria, such as those of typhoid fever and cholera, do not find a favorable field for development in ordinary river waters. The tendency is for them to die out; in fact the tendency of almost all forms of bacterial life is to perish rather than to develop in large and still bodies of deep water of the character of most of our river waters. The conditions for bacterial life as for all other vegetable life of course are very complex, and while certain of these necessary conditions are well known, others are entirely hid from us. The presence of light, the stillness of the water, the using up of certain necessary chemical constituents, and perhaps the presence of other organisms tend to the destruction of the bacteria. But, whatever the causes may be, the fact is well recognized that not only in reservoirs but in the distributing mains the number of bacteria tends to diminish. There are, however, two exceptions to this general rule. Shallow reservoirs where there is much organic matter may further rather than decrease the growth of bacteria, and "dead ends" and other portions of the distributing service where there is an accumulation of sediment may serve as breeding grounds for bacteria. These facts are shown in Providence where the water in the Sockanosset reservoir contains fewer

bacteria than the river water although this reservoir is small and the water does not remain there long. In the Hope reservoir, on the contrary, the amount of water is large, so large that it is not entirely renewed in the space of three or four months. In this reservoir tests carried on during a year showed that the bacteria were only one-tenth as numerous as in the water of the Pawtuxet river at the pumping station. The diminution of the number of bacteria by storage is, among other causes, due to two well recognized agencies. The first of these is time, which gives opportunity for the natural death of the organisms; the other is sedimentation, the bacteria being carried to the bottom partly by their own weight and partly by the falling of other and larger particles. Once at the bottom, they tend in the course of time to there perish. It is possible at times also that the development of the lower forms of animal life, such as the infusoria and crustacea, may result in the direct destruction of the bacteria by these animal organisms. It is evident then that storage cannot be relied on to furnish a safe method of purifying water; but that it is of practical value is shown by the surprisingly low death-rate from typhoid fever in certain cities which make use of water which is in a certain degree polluted but in which the water is a long time in reaching the consumer on account of the large reservoirs and the length of the mains. New York and St. Louis may be instanced as such cities.

2. Aeration. It was long believed that the excessive æration of water reduced in a decided degree the amount of organic material dissolved in it, and it was thought also that it was hostile to the growth of the lower forms of vegetable life, including the bacteria. Careful experimenting in the artificial æration of water by the Massachusetts State Board of Health has demonstrated that it has little or no effect in decreasing the organic ingredients, and Professor Leed's experiments upon the water both above and below Niagara Falls, where a natural æration is carried on on a most stupendous scale, showed that there was no chemical purification. There have been few tests to show the relation of aeration to bacterial life, but such as there are tend to show that it has no influence one way or the other. While forced aeration does not have any effect upon the albuminoid ammonia or on the number of living organisms in the water, yet it does not follow that it is not occasionally

of very great practical value. Water which has been rendered somewhat offensive to taste and smell by the growth of algæ and other organisms may be rendered palatable and so far as we know wholesome by æration. The forced æration of a water under pressure will drive out other gasses which are dissolved in it, and as taste and odor are due to the presence of such gasses they may be removed by æration. Even strong sulphurated hydrogen water and sewage may be rendered entirely sweet by passing a current of air through them, and waters which are only moderately contaminated by the offensive products of vegetable life are in a practical manner vastly improved by æration.

3. Sedimentation. It is of course a general law that all solid particles heavier than water when suspended in water tend gradually to settle to the bottom, the rate of settling depending upon the size and nature of the material. This simple precipitation of the organisms themselves to the bottom has been shown to be an important factor in the so-called self-purification of rivers and reservoirs. Organisms being once carried to the bottom remain there unless otherwise disturbed until some or perhaps all of them entirely perish. That however pathogenic organisms may retain their vitality for some time at the bottom of large bodies of water has been shown by experiments upon the mud and deep waters of Lake Geneva, in which living typhoid bacilli were found which must have come from the sewage which had found its way into the lake. At best the sedimentation of such minute organisms which so nearly correspond in density to the density of the water and which in many instances are exceedingly motile, is only partial. But it is a well known fact that heavy particles by their falling tend to carry down others which are lighter and of themselves would precipitate more slowly. This fact has been made use of both in the experimental and the practical purification of water. The experiments of Dr. Frankland show that the agitation of water with such materials as chalk, charcoal, and coke, and the subsequent subsidence for forty-eight hours resulted in the removal in many cases of a large number of the organisms. The removal of bacteria by means of an artificial precipitation in the water is accomplished with by far the best results when the precipitating substance is formed in the water by chemical changes. The formation of the particles that precipitate, by entang-

ling the organisms as the precipitate forms, and by the attraction of the particles for the organisms and the subsequent subsidence of all together, is very effectual in carrying the germs to the bottom. Processes are in vogue for the softening of water which consist in the precipitation of the lime in the form of a carbonate. One of these processes, called Clarke's Process, is in operation on a large scale in many water works in England. Dr. Frankland experimented with this process in the laboratory and also examined it biologically as carried on practically in various places in England. He found a very large reduction in the number of bacteria in the water by this process, sometimes the number removed being as high as ninety-eight or ninety-nine per cent. of the whole. Precipitation, however, has never been employed on a practical scale for the express purpose of removing the organisms from water. It is only shown to be undoubtedly of value in such cases as where Clarke's process was employed for other purposes. There are certain practical defects in this process and it has been shown that organisms can be more economically and efficiently removed in other ways.

4. Filtration. Under this heading I shall only refer to central filtration or filtration on a large scale by the corporation furnishing the water. Domestic filtration by means of small filters attached to the service pipes has been discussed before you in time past by Dr. Swarts, and perhaps before long he will report to you what progress has recently been made in this line. The filtration of water supplies on a large scale is carried on in three different ways.

First we have what may properly be called "natural filtration." By this method large wells are sunk or filter galleries constructed along the banks of streams or in the bed of the stream and the water of the river percolates through the natural strata of earth, sand, or gravel, as the case may be, into the gallery from which it is afterwards pumped.

Such filter galleries or filter wells are in use in quite a number of the smaller towns and cities of Massachusetts and in other parts of the United States. In Europe they exist chiefly in France, at Lyons, Toulouse, Nancy, and other places. According to the investigations of the Massachusettts State Board of Health this method of natural

filtration in the majority of cases in that state gives very excellent results. The water is clear, quite free from organisms of all kinds, though there is evidence that there is little or no oxidation of the organic matter taking place. In some instances, notably at Arlington, Wayland and Whitman, the character of the intervening soil is such that the water is not at all improved by this percolation, and sometimes is actually injured, the decomposition of the organic matter which takes place during its passage favoring the growth of crenothrix and similar organisms. In some cases where there is considerable silt in the river, as at Lowell, the filter gallery, though it may at first give excellent results, soon becomes so clogged that it is impossible to obtain the large amount of water needed. Among the successful filter galleries and wells in Massachusetts may be mentioned those at Newton, Brookline, Waltham and Attleboro. For small places where the soil is of proper character this method of natural filtration may often be advantageously employed; that it is entirely unsuitable to the larger water supplies of this state is the opinion of engineers.

The second method of filtration is by means of artificial sand filters. The English were the pioneers in this line of sanitary improvement, and the filters employed by the London water companies have long been considered models. Filtration was in 1855 made compulsory by act of Parliament for the metropolitan water companies. The severity of the cholera epidemic of 1848–1849, which was shown to be largely dependent on the use of pulluted water was the origin of this improvement. It was believed that the removal of foreign material from the water would decrease if not eliminate the danger of specific infection, and results have justified the expectation. Perhaps the best managed filters in the world, though they are sometimes run faster than they should be to supply the demand, are at Berlin. The following account is taken chiefly from a paper by Prof. Sedgwick on this subject:

"The first Berlin filters took water from the Spree at Stralau, but in 1877 new filters were constructed on the shore of Lake Tegel. The area of the four larger filters at the latter place is in round numbers 27,000 square feet each, that of the six smaller ones 21,000 square feet. The total filtering area is between five and six acres. The normal yield of the filter is roughly 3,000,000 gallons per day, per

acre. The filters are all covered and in order to keep the temperature as low as possible in summer they are protected with a layer of earth and grass. The filtering material consists of three layers. The lowest is about thirty centimeters thick, of rounded granite stones; upon this there rests a layer about thirty centimeters thick of coarse, clean, river-gravel free from sand, and upon this a layer about sixty centimeters thick of medium coarse sand. The average diameter of the sand grains is about one-third of a millimeter. Before the material is placed in position it is carefully cleaned from clay and dirt by special washings. Each filter is fitted with an under drain and with feed pipes. The filter is filled from below in order to drive out the air particles contained in the sand. This filling must be done slowly, for otherwise air will remain in spite of it, and will interfere with the successful operation of the filters by forming during its escape channels through which organisms can penetrate into the under layers of sand or gravel. The filtered water is drawn off beneath the several filters by under drains which convey it to a reservoir for purified water placed at such a depth as to receive the effluent by gravity. The ordinary process of filtration is conducted as follows: After a filter has been worked for a time it is found to have become clogged and allows the water to pass through only very slowly. The filter is then described as "dead," and must be cleaned. It is therefore drained and a gang of men is set to work on it with broad, thin shovels or with special "scrapers." Only the uppermost layer of sand and the dirt deposit, one-half inch or less in thickness, is removed. This dirt deposit is extremely interesting. It consists of a thin membranous layer of a greenish brown color, and so well defined that it can be easily peeled off in flakes from the sand below very much as a moistened postage stamp can be peeled from a piece of paper to which it has become partially attached. The sand below the dirt is clean and white to a very noticeable and striking degree. After the filter is filled with water from below to a depth of three or four feet the outlet is kept closed so that the supernatant water stands quietly upon the sand and is allowed to settle. This is a point of much importance, as the consequence of this setting is the formation of the delicate membrane of dirt upon the clean sand. After a time the effluent is allowed to escape, fresh, unfiltered water flows upon

the filter, and filtration proceeds. At first it is, of course, rapid and comparatively imperfect, but as the membranous deposit thickens, it grows slower and yields a better effluent. This early flow, therefore, is allowed to run to waste. The filtration continues with increasing head and diminishing rate until the dirt coating becomes almost impervious, when the filter is again said to be "dead," and once more ready for cleaning. Naturally at Berlin the scraping is so arranged as to remove as little sand each time as possible. Gradually, however, the sand layer grows thinner, and after a time it must be replenished with new (or washed) sand to the original depth. This happens about once in two years and requires considerable time. Even the ordinary "scraping" requires that the filter shall be out of connection for several days. At some seasons scraping is required very often (once a week) but in winter very seldom (once in two or three months). Ice on the water in the filter does not interfere with its working, only with its cleaning; and as this is not often required in winter, advantage may be taken of a warm spell, so that there is practically little difficulty on that score. There is considerable variation in European practice as regards size of the filter bed, the thickness of the sand, the height of the water upon it, the rate of filtration, etc. The thickness of the sand-bed and the fineness of the sand within certain limitations does not seem to exert any influence upon the value of the process. The height of the water is important in relation to the growth of algæ and other organisms, too great shallowness permitting the heating of the water in summer and an excessive vegetable growth. The most important factors are care in the treatment of the filter, its cleaning, and filling with fresh water, the formation of the dirt covering upon the surface through sedimentation, the allowing of the first water to run to waste, and lastly the rate of filtration. In general it may be said that the sand in well managed filters is from one to two feet in thickness; the water stands upon it about four feet deep, and is allowed to remain at rest for forty-eight hours before the filter is started. The time during which the first water is allowed to run to waste varies from three or four days to nearly three weeks in the case of the starting of a new bed or the entire removal of the sand. The question of the covering of filter beds is an important one. The covering is, of course, expensive, and interferes

to a certain extent with the cleaning, but it prevents the growth of algæ and other organisms and the contamination of the water by the decomposition of dead algæ.

The theory of continuous sand filtration in the manner described is that the dirt film upon the surface of the sand intercepts suspended matter, including bacteria and higher organisms, that the action of the nitrifying organisms in the sand and the dirt layer together with the action of the oxygen of the water in its slow passage through the sand result in the oxidation of a certain portion of the organic matter both suspended and dissolved. As a matter of fact we find that the results of continuous sand filtration are of great importance in improving water which is subjected to this process. This has been amply demonstrated not only in experimental filters, such as those of the Massachusetts State Board of Health at Lawrence which have been so carefully worked for a number of years, but also on a large scale in filters in various European countries. It has, of course, long been known that this method of sand filtration would remove the suspended matter which could be seen by the naked eye, that it would remove some of the coloring matter, though not to any great extent, and that it would decrease the amount of dissolved organic material from twenty to fifty per cent. It is only within recent years, however, that the development of bacteriology has rendered it possible to determine whether such filters can remove the active agents in the causation of disease. The experiments of Percy Frankland in England have demonstrated that the well managed filters of the London water companies remove from ninety-six to ninety-nine per cent. of the bacteria. The Berlin water supply has since 1885 been subjected to bi-monthly bacteriological analyses, and it has been shown that these filters also on an average remove about the same proportion of organisms, though at times, on account of the excessive speed at which they are run, the work is not so satisfactory. The experimental filters at Lawrence give similar results with similar rates of filtration. It is these tests which have shown the great importance of the rate of filtration. The rate in London is about three million gallons per acre per day. In Berlin it is about the same, though at times greater. It is found that when the rate is increased the number of bacteria increases. In Zurich the rate has been from thirteen to fourteen millions of gallons

per acre, and the number of organisms removed from 1886 to 1890 averaged only ninety per cent. In other places where little attention is paid to the filters or where they are overworked, the number of organisms passing through varies greatly, and sometimes the number of organisms in the effluent is in excess of the number in the unfiltered water. The experiments of the Massachusetts State Board of Health have demonstrated that a rate from one and a half to two million gallons per acre can be relied upon to remove all pathogenic organisms from water under ordinary conditions. In the bacteriological experiments on large filters in practical use, some, if not all, of the bacteria found in the effluent water are due to growth in the under drains and effluent pipes. In the Lawrence experiments quantities of pathogenic bacteria, such as the typhoid bacillus, were introduced continuously into the filters in much the same way that the water would be contaminated in actual practice, and it was found that in most cases none at all passed through the filter, and in only one case where the rate was less than two million gallons per acre was the number removed less than ninety-nine per cent. By far the larger proportion of European cities which derive their water supply from polluted sources have a fairly efficient system of sand filtration; Paris, however, is a conspicuous example of a city which has a polluted water supply and until the present year at least has made no effectual effort to improve it. In this country there is no good sand filter in use at the present time. One was constructed at Poughkeepsie, but was not adequate and was not properly cared for, and one is now in process of construction at Lawrence. Something can be learned of the practical value of these filters by considering the prevalence of typhoid fever in cities which filter their water and those which do not. As examples of cities which drink a water known to be polluted to a considerable extent with human excrement may be mentioned Paris, in which the death rate from typhoid for a number of years past was 9.5 per 10,000 of the population. In Pittsburg it was 9 per 10,000, in Cincinnati 6.9, in Chicago 6.9, in Philadelphia 6.2, in Lowell 8.8, in Lawrence 8.6. The death rate from typhoid fever in the great cities of London and Berlin, both using sand filters, may be cited in contrast. For London it was 1.08 and for Berlin it was 2.05 per 10,000. In the city of Antwerp, whose water is filtered

by the Anderson process, there has not been much typhoid fever, although the water is grossly polluted, and in Zurich and Buda-Pesth the introduction of filtration has markedly diminished typhoid fever. Perhaps the most striking illustration of the value of sand filtration is shown in the case of Altona and Hamburg. These cities are contiguous, in fact they may geographically be considered one city. Both take their water supply from the river Elbe, which also receives their sewage, while as Altona is below Hamburg the water there is much worse than it is at the Hamburg intake. Yet in the epidemic of cholera last summer there were in Hamburg 287 cases to 10,000 of the inhabitants, and at Alton thirty-nine cases per 10,000. Moreover investigation showed that a large proportion of the cases in Altona were imported cases from Hamburg.

It is often argued that because disease germs are living and capable of rapid reproduction that the removal of a portion, even though it be as much as ninety-nine per cent., can be of little avail. And this would doubtless be true if water were a suitable medium for their growth. But we have seen that it is not. Therefore the removal of a high percentage of organisms should diminish the chance of disease in even a greater proportion. And this is amply borne out by the statistics of the practical results of filtration given above.

It has been estimated that the cost of sand filters for the daily supply of 10,000 gallons for this city would be about $500,000, and that the running expenses, including the interest, would amount to from eight to ten dollars per million gallons filtered.

The last method of filtration which we shall consider is in conjunction with precipitation. I have already referred to the value of precipitation in removing micro-organisms from water, and stated that this process was not entirely practicable by itself. The attempt has been made to combine it with filtration in the iron or Anderson process. This process has been in use for a number of years in Antwerp, Dordrecht, and several other places. At first iron was used in the filter bed, but experience showed that this was not practicable, and therefore another method was devised. The apparatus as described by Mr. Anderson in a paper read at the last International Congress of Hygiene, consists of a cylinder, either of cast iron or built up like a boiler of riveted

plates, supported horizontally on two hollow trunnions, one of which forms the inlet, the other the outlet for the water. Running inside the shell of the cylinder from one end to the other are a number of curved shelves or scoops. A quantity of metallic iron in small pieces is placed inside the cylinder, which is then slowly rotated while the water to be treated flows through in a continuous stream, thus being brought into intimate contact with the iron while at the same time the iron is itself kept clean and active by its continual friction and movement. The nature of the action which takes place within the cylinder is not known positively, but the most likely theory is that the water, by means of the carbonic acid and oxygen which it contains in solution, acts upon the bright metallic iron, forming ferrous oxide, ferrous carbonate being an intermediate product. The water on leaving the purifier contains a quantity of iron, amounting to about two-tenths of a grain per gallon, partly as ferrous and partly as ferric oxide. The water is next aerated. During this aeration the ferrous oxide is entirely converted to the ferric state and subsides to the bottom, carrying with it a large proportion of the organic matter whether suspended or dissolved. The water is next conveyed to a shallow sand filter, by which the finer particles of the iron precipitate are strained out. A fine film of oxide is left on the surface of the filter, and this appears to perform two very important functions—viz., the arrest of the "free ammonia" and of microbes, which are both powerfully retained by the closeness of the film. There are very few data at hand to show the effect of this process of purification except such as have been furnished by parties more or less interested in it in a commercial way; but there seems to be no doubt that it will remove as large an amount of organic material from the water as any other process. How it acts in removing the color I am unable to say. According to the experiments on the Antwerp filter and upon the experimental filters in Paris and Philadelphia, it is fully as efficient as an ordinary sand filter in removing bacteria. This process is worthy of note also for its economy, it being considerably cheaper than simple sand filtration, for owing to the gathering of the flocculent precipitate upon the surface of the filter it is possible to pass the water through it at a much higher rate than could otherwise be done. This process, however, is not applicable to all waters, or at least not without some

modification. At the Boston water works it was found to be entirely inapplicable to the water supplied to that city. It seems to require the presence of carbonic acid gas or at least of carbonates in the water, and our waters are rather deficient in these constituents. This process has never been employed on a large scale in this country.

A method of purifying water has been in vogue for some years which makes use of sulphate of alumina for causing an artificial precipitation. The action of the alumina is two-fold. A part of it is decomposed, forming sulphates of other bases and a flocculent precipitate of aluminic hydrate. A part of it also combines directly with some of the organic matter present in the water, coagulating the same and thus helping to increase the precipitation. If the theory is correct and if the usual ingredients exist in the water in proper proportion, all of the sulphate of alumina or its derivatives would be removed in the bed of the filter and none should be found in the effluent water. This is known as "mechanical filtration," though it might better be described as chemical, and it is this method which a commission appointed by the City Council of Providence is now investigating. These mechanical filters may be of almost any size or shape; the prevailing forms, however, are either circular wooden or iron tanks about twelve feet in diameter or closed cylinders six to eight feet in diameter. Sometimes these filters are arranged to act by gravity alone, as do the simple sand filters, and sometimes they work under a pressure, in which case of course the tank has to be closed. The bottom of the tank contains a large number of openings guarded by screens or valves which permit of the outward passage of filtered water and yet retain the sand, and also permit of a powerful reverse current which will stir up and wash the sand in the process of cleaning. In some filters, the cleansing process is hastened by means of some mechanical contrivance for stirring the sand during washing. The sand in the different filters varies from two to four feet in depth. It is much coarser than that in the simple sand filters, and sometimes a crushed quartz is used instead of sand. The filter is started by turning on the water and also the solution of sulphate of alumina. Sometimes it is also necessary to add lime or carbonate of soda in order to decompose the sulphate of alumina quickly and completely. For a varying period, amounting in the case of our experiments here

to about fifteen minutes, the effluent water is allowed to run to waste while the film of precipitated material is forming on the surface of the sand. The filter then continues to run at the rate of about 125,000,000 gallons per acre for a period of twenty hours, when it becomes so clogged that it is necessary to wash it by reversing the current and sending filtered water rapidly up from the bottom. The washing process usually takes about fifteen minutes. There have not been any thorough tests of these filters previous to those now in progress in this city. The chemical tests that have been made would indicate that there is a diminution of from seventy to eighty per cent. in the organic matter. The visible suspended matter is almost entirely removed, and the color is either completely removed or very nearly so. Very few tests have been made to determine the value of these filters in removing micro-organisms, but since we have been experimenting here I think we have determined that we can reasonably rely upon this style of filter to remove organisms as well as any other method. The effluent water has been shown to contain no trace of the applied alumina salt. The cost of a filter plant of this kind for the daily supply of 10,000,000 gallons would be probably not much over $125,000, and as nearly as can be estimated the running expenses, including interest on the plant, would be about $5 per million gallons filtered.

In conclusion I would say that we can positively affirm that if it is necessary for a municipality to make use of a polluted source for its public water supply, it is necessary that the water should be filtered before it is delivered to the consumer; and, second, that we can be assured that in filtration we have a method by which all, or nearly all, of the dangerous material can be removed from the water. Both theory and practice have amply demonstrated that water so treated is practically a safe water to use for drinking. It is also of interest to know that the cost of a proper system of filtration is not prohibitive, and that so far as Providence is concerned enough money is now spent upon spring waters to filter the whole public supply for the inhabitants. The exact form of filter which is most applicable to the water supply of this city has not yet been determined, and I believe that every town must work out for itself this problem. But it seems evident that efficient filtration in one form or another must come to be generally practised in the United States as it now is in Europe.